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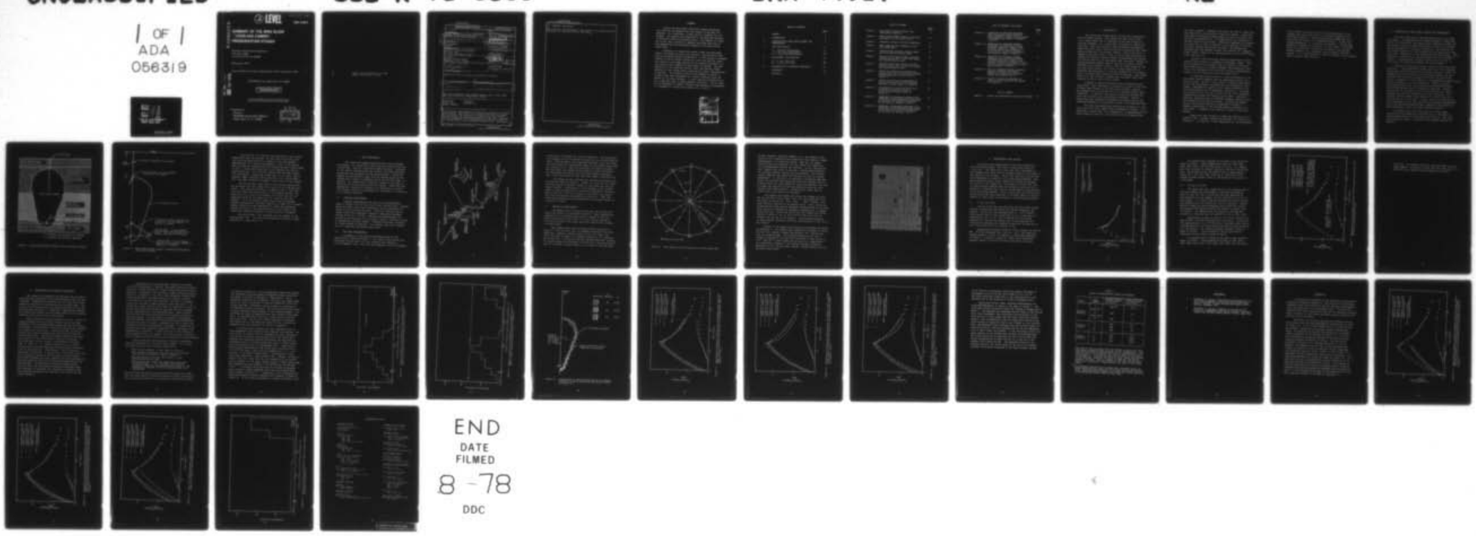

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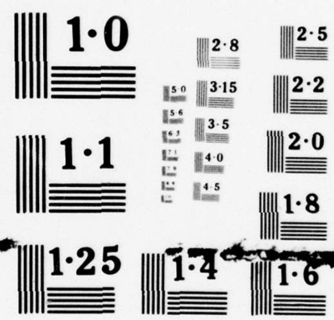

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SUMMARY OF THE MING BLADE TRACER-GAS CHIMNEY PRESSURIZATION STUDIES

Systems, Science and Software
P.O. Box 1620
La Jolla, California 92038

December 1977

Topical Report for Period September 1977—December 1977

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Porous Flow	Permeability
Nuclear Chimney	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two tracer-gas pressurization studies were conducted in the Ming Blade chimney. The objectives of these tests were to evaluate gas flow within the chimney and to measure the flow from the chimney through the surrounding material to the mesa. The relative gas permeability and accessible gas-filled void volume of the chimney material was estimated from this data. This report

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20. ABSTRACT (Continued)

describes the test procedures, test results, and chimney material properties as inferred from the test data.

SUMMARY

During the Ming Blade tracer-gas chimney pressurization studies, gas seepage from the chimney to the mesa was examined. Air containing a tracer gas was injected into the chimney. Gas samples were collected on the mesa and analyzed to determine tracer gas concentrations. The absence of tracer gas in all the collected air samples indicates there was no gas seepage from the Ming Blade chimney to the mesa during these tests.

Pressures and tracer gas arrival times were monitored within the chimney at points of interest. These results were used to determine material properties. If the chimney is assumed uniform in the horizontal direction, then flow from the injection region to the upper portion of the chimney occurred as if the relative gas permeability were about 10 darcies. The permeability in the injection region, lower and possibly upper portions of the chimney were significantly higher (approximately 50 darcies). The chimney could also be modeled as having a uniform inner core surrounded by a highly rubblized layer adjacent to its outer boundary. In that case the permeability of the rubblized layer is approximately 50 darcies. In all cases it was necessary to assume a relative gas porosity corresponding to a chimney air filled void volume of 5.4×10^5 m^3.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

1. INTRODUCTION

Two tracer gas pressurization studies were conducted in the Ming Blade chimney. The possibility that future tests (i.e., Diablo Hawk) may be conducted in the near vicinity of existing chimneys (i.e., Mighty Epic) provided the impetus for this work. When the separation distance between chimneys becomes relatively small, there exists the possibility that cavity gases may seep into an existing chimney. Should this occur, a number of questions arise. First, do these gases percolate up through the chimney, diffuse through the paintbrush and caprock and finally leak into the atmosphere above the mesa? Second, do chimney pressures become large or can the gas easily diffuse throughout the chimney so that it acts as a dump volume to contain the cavity gases? The intent of these studies was to determine the properties of a typical chimney and its surroundings in the hope these questions could be answered. Ming Blade, which is in the vicinity of Mighty Epic and Diablo Hawk, was selected by DNA for this initial study.

A number of specific objectives were addressed during these tests. Most importantly, the ability of gas to flow from the Ming Blade chimney to the mesa was evaluated. Relative gas permeabilities and porosities of the chimney material were determined. In addition, the extent to which the chimney material was fractured was qualitatively evaluated. Finally, a brief study was conducted to determine the sensitivity of the predicted permeability and porosity values to the measured data.

The first and second Ming Blade tests initiated on 7 July 1976 and 20 July 1976 respectively, proceeded as follows. Air containing a tracer gas, at a concentration of approximately 10^{-4} parts tracer per part air, was injected into the chimney from the tunnel complex. Pressures and tracer gas arrival times were then measured at various points within the chimney. These data were used to determine chimney properties such as relative gas porosity and permeability. Air samples were also collected at various locations on the mesa. These were examined for evidence of tracer gas in order to provide a direct measure of any communication between the chimney and mesa. Gas samples were analyzed using the Systems, Science and Software (S^3) chromatograph, which is sensitive to concentrations as low as 10^{-12} parts tracer per part air.

Results of the Ming Blade chimney pressurization study indicate this chimney is a competent containment vessel. There was no evidence of gas seepage from the chimney to the mesa. The chimney material is highly permeable and extensively fractured. Its accessible air filled void volume is approximately a factor of five larger than the Ming Blade cavity.

In the report which follows, a brief description of the Ming Blade chimney geometry and the surrounding geology will first be given. Section 3 will include a complete description of the test procedures, instrumentation and measurement techniques. Experimental results for all tests conducted on the Ming Blade chimney will be presented in Section 4. Included in this section are results of tests carried out to determine communication between the chimney and the mesa. Analytical-numerical techniques used to determine chimney properties such as accessible air filled void volume , relative gas permeability, and fracture extent are presented in Section 5. A complete description of the inferred material properties is given there. A summary of all results is given in the final section.

These tests were carried out under the direction of Joe LaComb of DNA. Systems, Science and Software (S^3) served as a consultant. In addition, S^3 was responsible for the performance of the tracer gas studies and for the interpretation of the pressure and tracer gas results to determine properties of the chimney material. The following report summarizes the S^3 activities and results in considerable detail. To make this summary meaningful, it is, however, necessary to include some background information concerning the test itself. A minimum amount of information is therefore included on the geology, chimney geometry, test equipment, test procedures and test results. It is anticipated that DNA will provide a more complete report covering these subjects.

2. DESCRIPTION OF MING BLADE CHIMNEY AND SURROUNDINGS

The Ming Blade chimney and surrounding strata are shown in Figure 1. An estimate of the chimney geometry is made from drill-back information. The working point location is known and positions at which the three drill holes intersect the chimney can be estimated from drilling information. The remainder of the chimney geometry is then extrapolated from these four known positions. Properties of the chimney material are unknown. Some approximate properties for the surrounding strata are shown in Figure 1. These material property values are given here to illustrate the differences between the various layers.

Material property data shown in Figure 1 were taken from Reference 1. They represent TerraTek data taken from competent samples obtained from the UE12n #9 exploratory hole. Values of permeability were determined from oven dried samples and consequently are likely to greatly overestimate the gas permeability of competent in-situ material. Gas permeability data are also shown in Reference 1 for saturated tuff. There is a gross discrepancy between dry and saturated tuff permeability with values differing by about two orders of magnitude. However, the presence of fractures in the in-situ material may greatly increase the effective permeability of the formation. Preliminary testing, based on the Dining Car U-12e.18 PS#1 hole indicate this to be the case. In fact, whole hole permeability tests conducted on this hole indicate the relative gas permeability of the paintbrush material may, indeed, be very similar to the permeability of the oven dried competent material.

Interpretation of the test data is, in many cases, sensitive to the condition of the drill hole. Therefore, a detailed description of these holes will be given. The three drill holes are shown in relation to the chimney geometry in Figure 2.

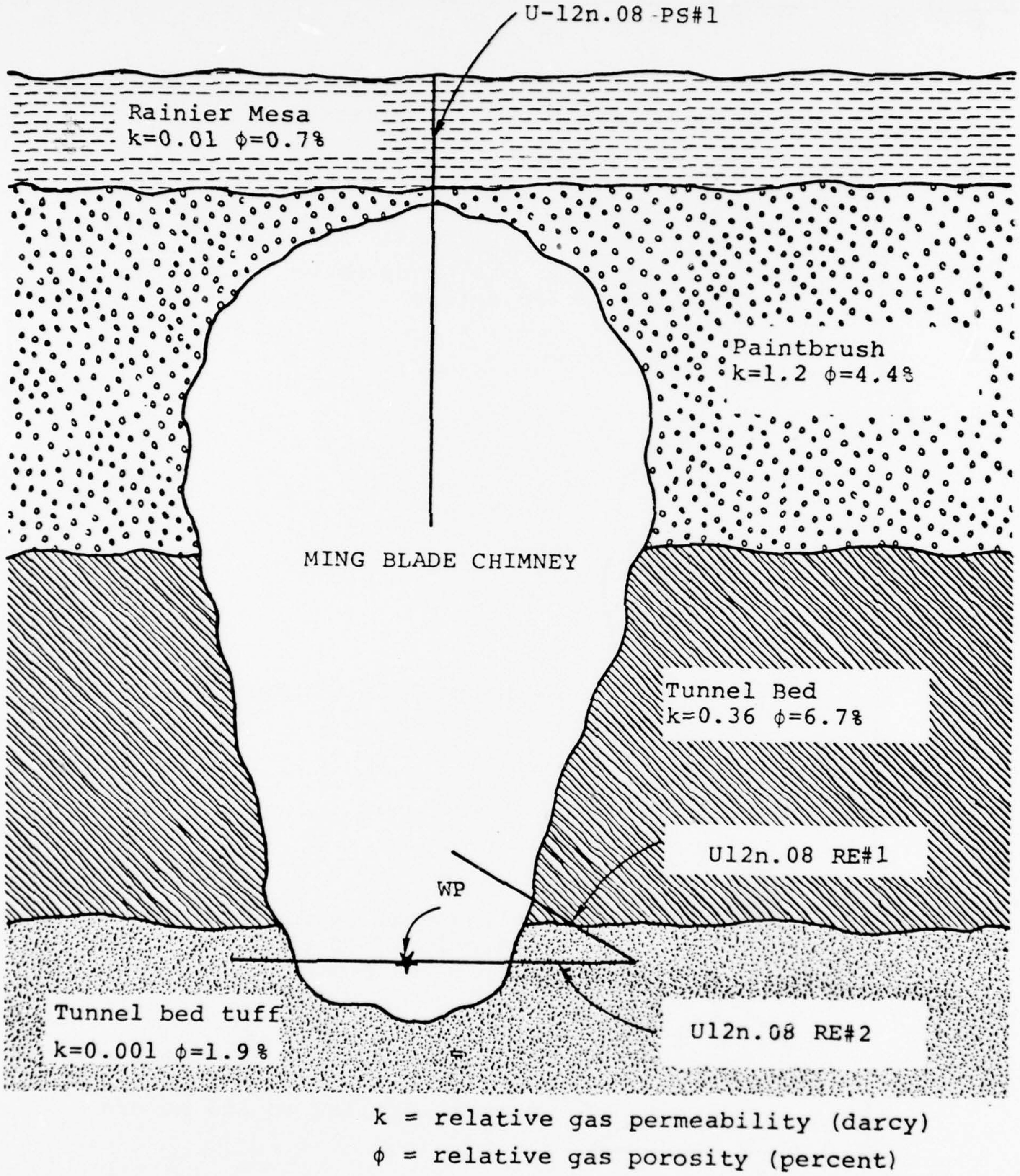


Figure 1. Ming Blade chimney geometry and surrounding geology.

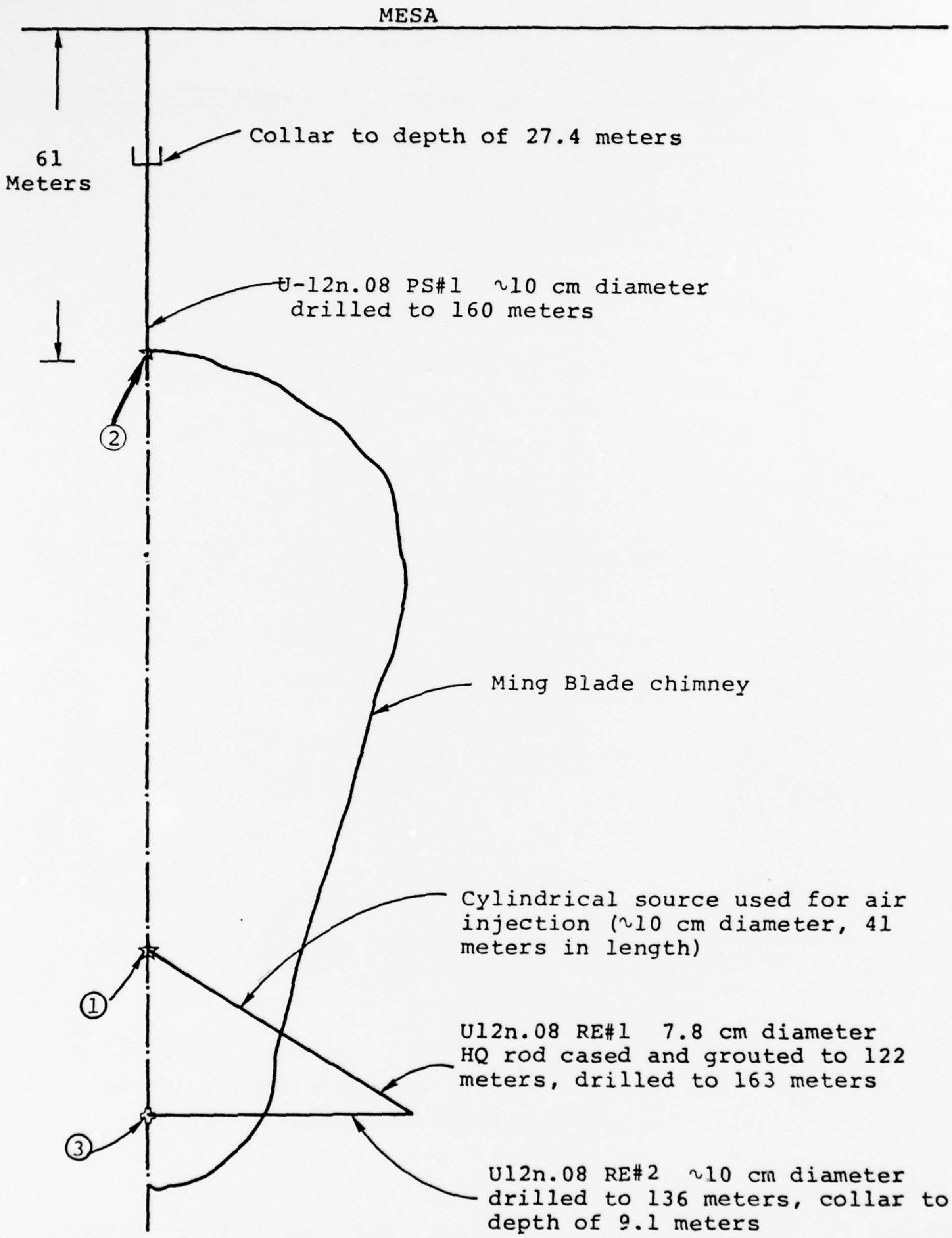


Figure 2. Ming Blade chimney showing a detailed description of all drill holes.

U-12n.08 PS#1 is a vertical hole beginning at the surface ground zero (SGZ) on the mesa. At the time of the first test this hole had been drilled to a depth of 49 m and extended approximately 4.6 m into the paintbrush. Prior to the second test the hole was extended into the chimney and had a total length of 160 m. During both tests this 10 cm diameter hole was uncased except for a 27.4 m collar leading from the mesa surface into the caprock. During the second test, a 61 m long, .024 cm diameter copper capillary tube installed in the U-12n.08 PS#1 hole, was used to obtain gas samples from the top of the chimney.

The U12n.08 RE#1 hole began in the U12n.08 bypass drift and continued into the chimney at an angle of 33^{o} from the horizontal. This hole was drilled to a depth of 163 m. The first 122 m was cased and grouted using 7.8 cm diameter HQ rod. The remaining 41 m of this 10 cm diameter drill hole was left uncased and served as the source for air injection into the chimney. A 1.27 cm diameter copper tube, used for downhole pressure measurements, had been inserted to a depth of 116 meters. Further insertion proved impossible as rubble had apparently entered the HQ rod. The uncased portion of this hole in the chimney was therefore probably at least partially collapsed.

The U12n.08 RE#2 hole extended into the chimney to the working point (WP). This hole was uncased but did have a collar extending to a depth of 9.1 m.

3. TEST DESCRIPTION

The tracer gas chimney-pressurizaiton tests proceeded as follows. Air containing a tracer gas was injected into the U12n.08 RE#1 hole for a specified number of hours. Pressures at the source, working point and vertical hole were monitored during both the pressure rise and decay periods. Tracer gas samples are periodically taken from the working point and the chimney top in order to determine tracer gas arrival times. In addition, air samples were collected at points on the mesa to determine if gas was seeping from the chimney. These data were subsequently analyzed to determine the accessible air filled void volume, relative gas permeability, and extent of fracturing of the chimney material.

3.1 PRESSURE MEASUREMENTS

Pressure measurements were made at points 1 and 3 as shown in Figure 2 and at the U-12n.08 PS#1 vertical hole. Measurements were made using water manometers, mercury manometers or gauges as the situation dictated. Sensitive readings were obtained using water manometers capable of measuring pressures ranging from 0.07 to 20 KPa. Recording microbarographs were located on the mesa and in the tunnel in order to provide a record of atmospheric pressure changes. Manometer data were corrected for these changes as required. All pressure data were recorded by H & N personnel throughout these tests.

3.2 FLOW RATE MEASUREMENTS

A schematic of the injection apparatus used for the second test is shown in Figure 3. Air, used as the carrier gas, was piped from the portal to the injection site through a 15.2 cm diameter line. This line was reduced to two 5 cm diameter

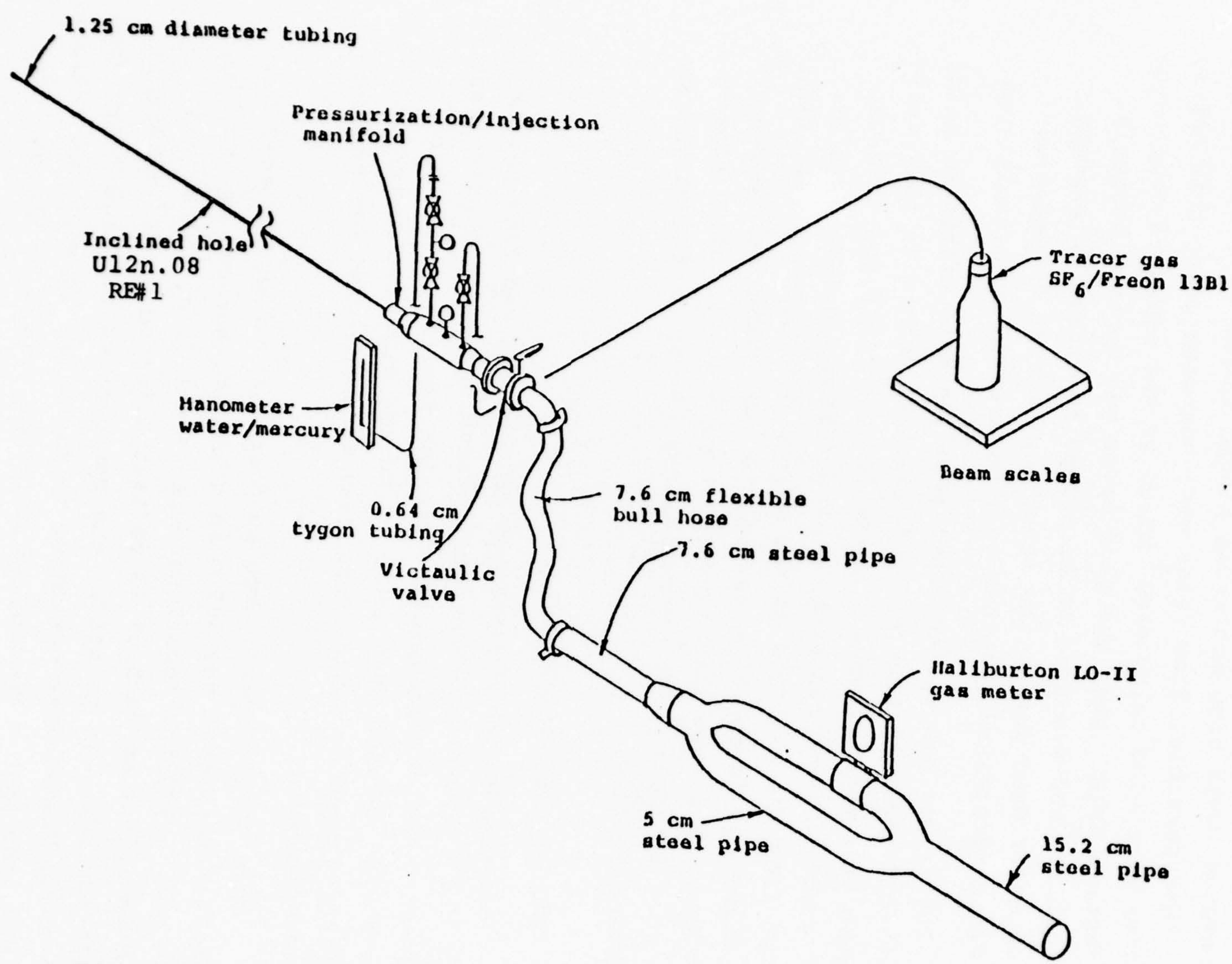


Figure 3. Schematic showing injection apparatus.

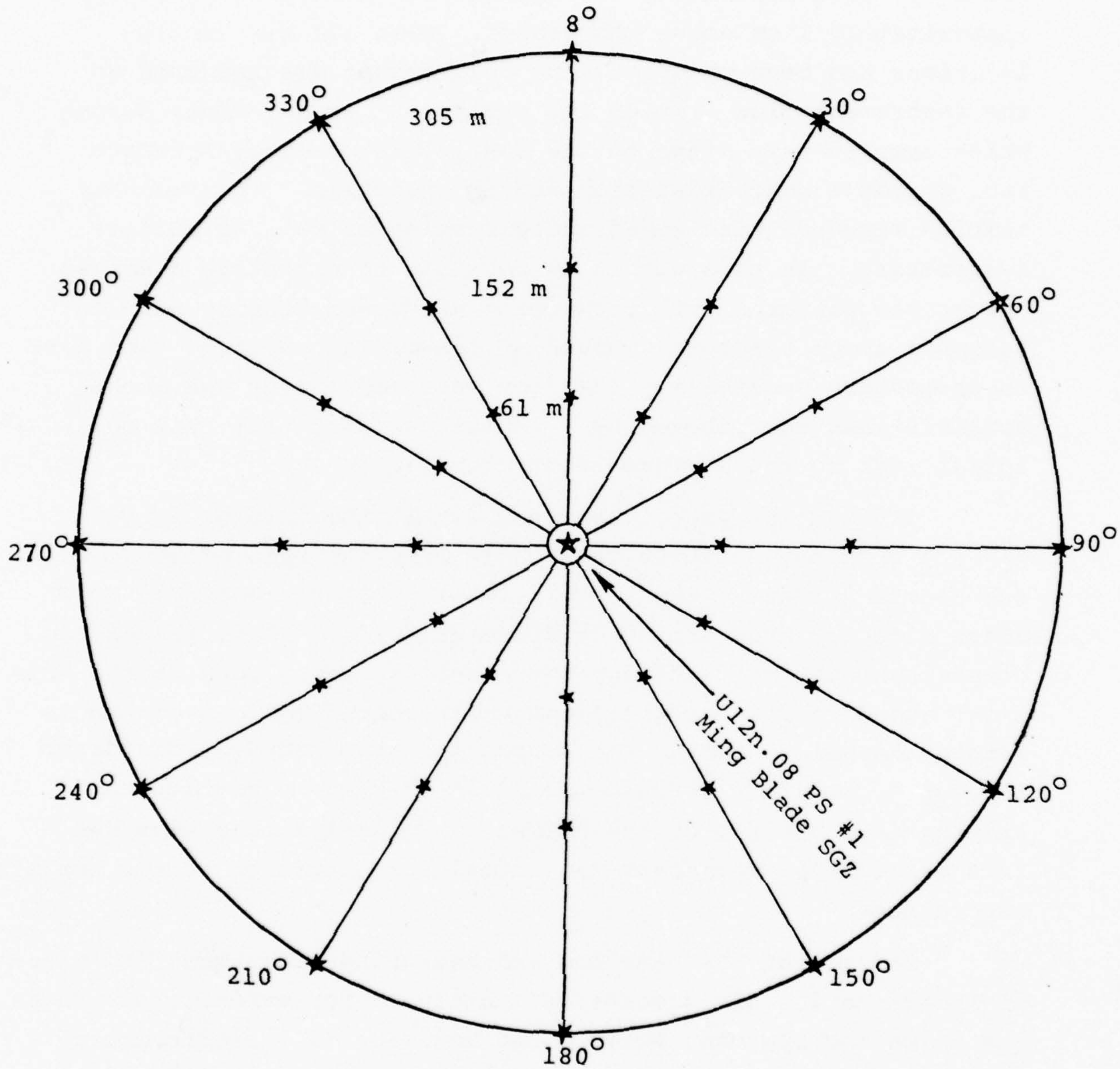
lines prior to reaching the injection manifold. The Halliburton 5 cm diameter LO-II flow meter was placed in one of these smaller lines. When possible, flow rates were measured using this meter. Flow rates were also calculated[2] based on the pressure drop along the injection hole. When the flow meter was working properly, the calculated and measured rates agreed to within 10 percent. The flow meter used during the first test proved inoperable, thus, rates determined for that test were based on calculations.

The tracer gas was injected into the main airstream using the manifold shown in Figure 3. Almost all joints in this manifold were welded to prevent leakage of the tracer gas into the tunnel complex. Unfortunately, a few threaded joints existed. These go from the manifold to the valves connected to the manometer lines and to the line leading to the tracer gas source. The tracer gas bottle was placed on a beam scale. Mass flow rates were determined from measurements of the bottle weight as a function of time.

3.3 TRACER GAS MEASUREMENTS

Gas samples were collected on the mesa and from points within the chimney at prescribed intervals. These samples were returned to the instrumentation station located at the Ming Blade surface ground zero (SGZ) or to the station located in the U12n.08 reentry drift where they were analyzed for evidence of tracer gases.

Mesa samples were taken at points shown on the grid in Figure 4. This grid was 305 m in diameter centered on the Ming Blade SGZ. Sampling locations were at the 61 m, 152 m, and 305 m positions on each of 12 radials oriented at 30° intervals and at the SGZ. In practice, one man carried sufficient syringes in a small basket-like container to allow him to walk two radials; one out, and then a second radial on his return to the SGZ area.



★ Sampling positions

Figure 4. Mesa sampling grid centered on the Ming Blade SGZ.

At each location, replicate samples (i.e., two samples) were drawn by first aspirating the syringe and then drawing a sample approximately 1 cm above the ground. When all six sample locations had been occupied, the full basket was returned to the instrumentation station for analysis. At all times during which samples were drawn on the mesa, a Meteorology Research Inc. portable weather station was in operation. This weather station measured wind speed and direction as well as outdoor temperature. In this way it is possible to correlate observed tracer gas patterns with prevailing winds and thereby make inferences about the total amount of tracer gas observed and also to assess the possibility that any observed tracer gas was a spurious leak contributed by a tunnel portal rather than an actual leak to the surface of the mesa.

Gas samples were taken from within the chimney at point 3 and from the U-12n.08 PS#1 hole into the paintbrush (i.e., see Figure 2) during the first test. These samples were drawn directly from the 10 cm diameter holes. Thus, tracer gas concentrations found therein represent concentrations at the hole inlet and do not necessarily represent concentrations at depths within the hole. During the second test gas samples were drawn through a capillary line in the U-12n.08 PS#1 hole which extending into the top of the chimney. Concentrations measured in these samples represent the actual concentration at the top of the chimney.

Details of the sampling and measuring techniques are given in Reference 2. Air samples were analyzed for evidence of tracer gas using the Systems, Science and Software (S^3) electron capture gas chromatograph. The ultimate sensitivity of the S^3 tracer gas monitor to SF_6 and Freon 13B1 used in these tests is $\sim 10^{-12}$ and $\sim 10^{-11}$ parts tracer gas per part air, respectively. As illustrated in Figure 5, this monitor provides excellent separation of the SF^6 and Freon signals, thereby allowing use of multiple tracer gases.

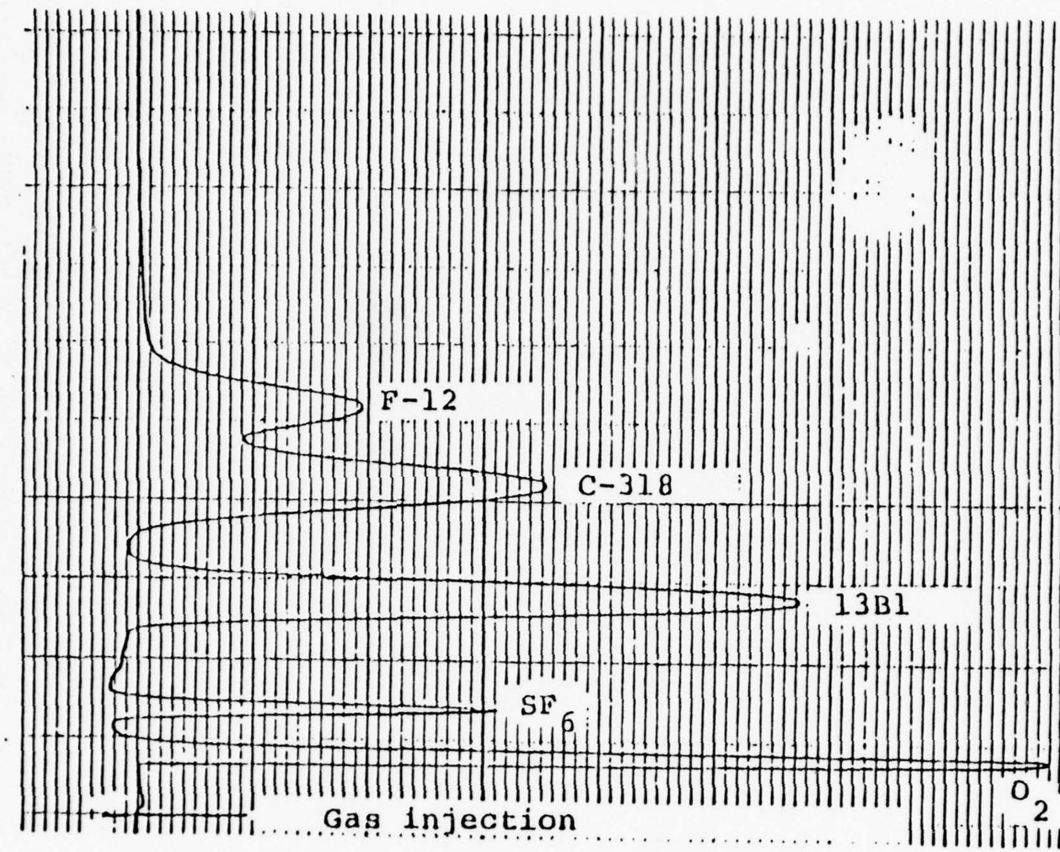


Figure 5. Chromatograph response showing separation of various tracer gases.

4. EXPERIMENTAL TEST RESULTS

Two tracer gas pressurization tests were conducted in the Ming Blade chimney. The first of these tests began on 6 July 1976. The objective of that test was to determine if gas seepage could occur from the chimney either to the bottom of the caprock or to the mesa. During this test the U-12n.08 PS#1 hole terminated at a depth of 4.6 m into the paintbrush. Thus there existed no drill holes connecting the mesa and chimney. The intent of the second test, initiated on 20 July 1976, was to again evaluate seepage from the chimney to the mesa and in addition to determine the relative gas permeability and porosity of the Ming Blade chimney. Prior to this test the vertical hole from the mesa had been completed to the depth shown in Figure 2. Results of these tests are discussed in the following sections.

4.1 6 JULY 1976 TEST

In this first test, gas flow from the Ming Blade chimney through the overlying paintbrush and caprock formations was studied. During this test approximately 2.3×10^4 standard cubic meters (SCM) of air, containing SF_6 as a tracer gas at a concentration of 2×10^{-4}, were injected into the chimney. Communication between the chimney and its surroundings was evaluated by analyzing air samples collected on the mesa and in the U-12n.08 PS#1 hole for evidence of SF_6.

Pressurization began at 0030 on 7 July through the U12n.08 RE#1 hole and continued until 0630 on 7 July. The resulting chimney pressure history, as measured at points 1 and 3 shown in Figure 2, is shown in Figure 6. There was no measurable pressure change in the U-12n.08 PS#1 hole during this test.

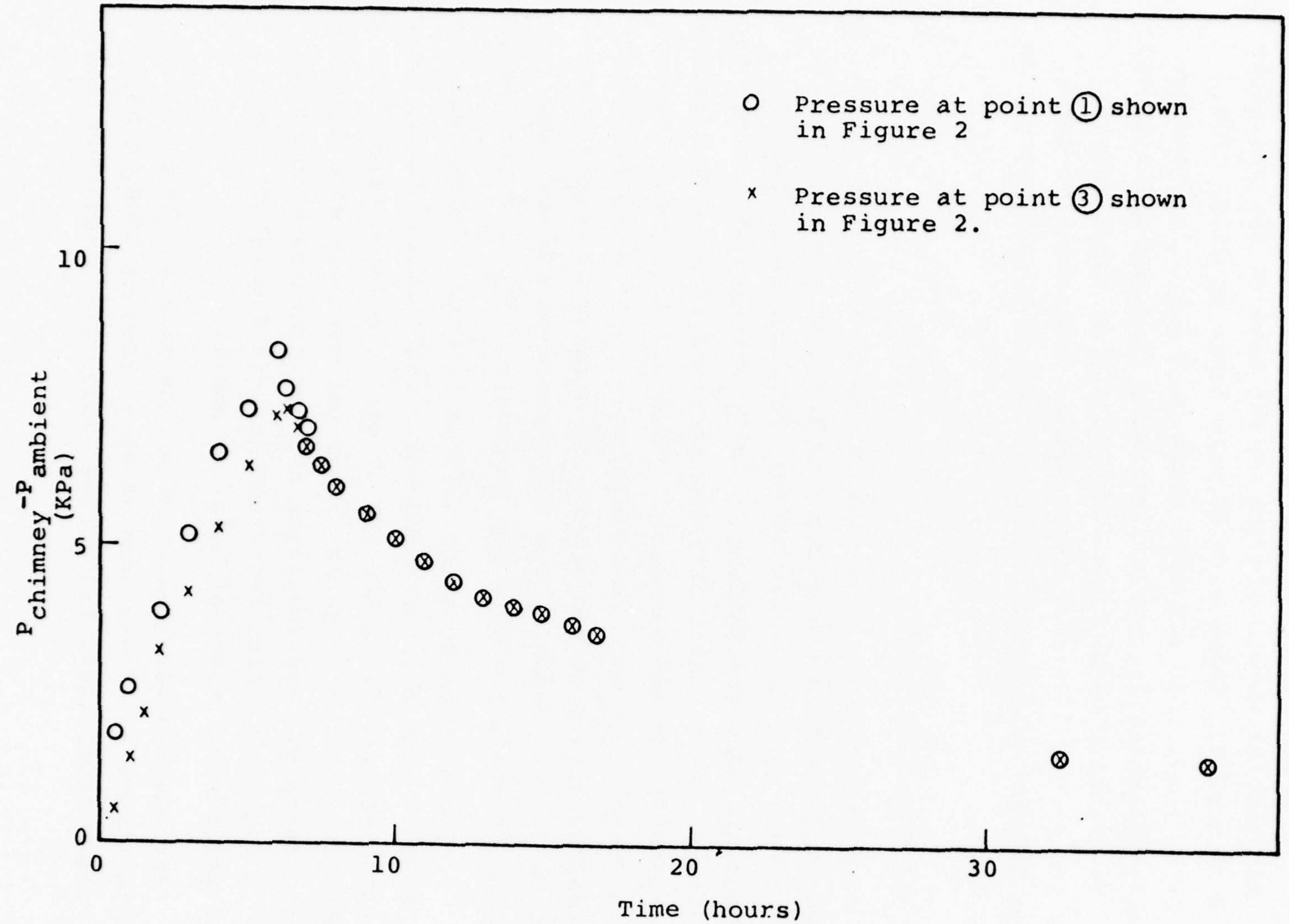


Figure 6. Measured Ming Blade chimney pressure history during the 6 July 1976 tracer-gas pressurization test.

Air samples were collected on the mesa at the positions shown in Figure 4. These samples were taken at 0600, 0700, 0800, 0900, 1000, 1100 and 1900 hours on 7 July. Air samples were also collected at regular intervals from the U-12n.08 PS#1 hole. No evidence of SF_6 was found in any of these samples. During the 6 July 1976 test there was no indication of gas seepage from the chimney either to the bottom of the caprock or to the mesa.

4.2 20 JULY 1976 TEST

The second test was a duplication of the previous test in that gas seepage from the chimney to the mesa was examined. Prior to this test the U-12n.08 PS#1 hole was completed so that pressures and gas samples could be obtained at the top of the chimney. As a result data was obtained from which relative gas permeabilities and porosities could be evaluated. Chimney material properties were determined using tracer gas arrival and pressure data obtained within the chimney at points shown in Figure 2. Gas seepage from the chimney to the mesa was evaluated by analyzing mesa air samples for SF_6 or Freon 13Bl.

Pressurization began at 0215 on 20 July 1976 through the U12n.08 RE#1 hole and continued until 1600 hours. During this time approximately 5.4×10^4 SCM of air containing Freon 13Bl at a concentration of 10^{-4} parts tracer per part air were injected into the chimney. The resulting chimney pressure history is shown in Figure 7. Also indicated in this figure are the tracer-gas arrival times at holes #2 and #3.

Air samples were collected on the mesa at the positions shown in Figure 4. These samples were taken at 0600, 0700, 0800, 0900, 1000, 1200, 1330, 1500, 1630, 1800, and 1900 hours

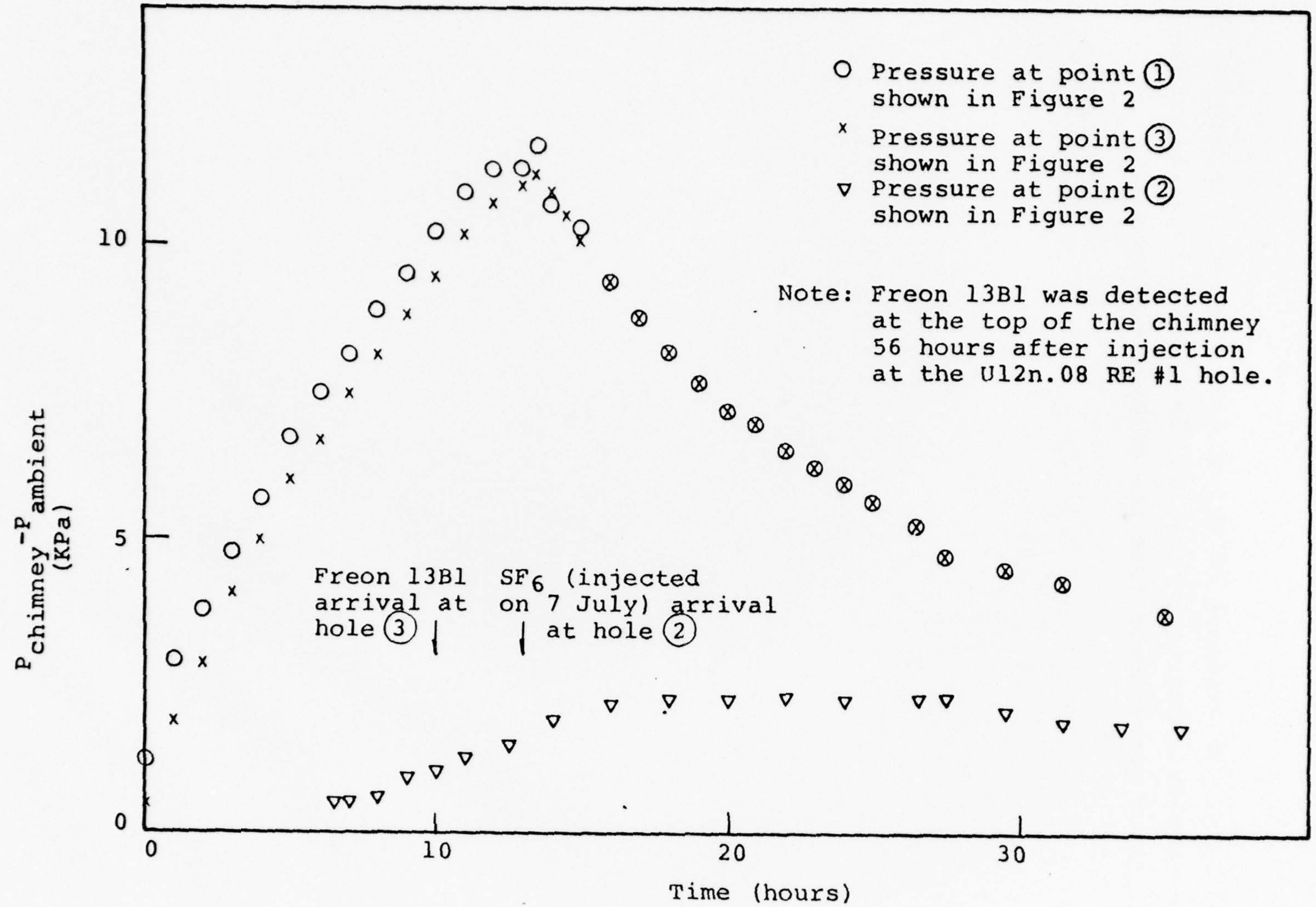


Figure 7. Measured Ming Blade chimney pressure history during the 20 July 1976 tracer-gas pressurization test.

on 20 July. No evidence of SF_6 or 13B1 was found in any of these samples. During the 20 July 1976 test there was no indication of gas seepage from the chimney to the mesa.

5. DETERMINATION OF MATERIAL PROPERTIES

The tracer gas pressurization technique may be used to determine the properties of the chimney material and its surroundings. Quantitative evaluation of the relative gas permeability and porosity distributions can be determined. The extent of fracturing within the chimney material can also be qualitatively evaluated. In addition, communication through the chimney and through the surrounding media can be directly measured by monitoring tracer gas arrival.

Media properties were determined as follows. First the chimney geometry and surrounding geology must be defined. Preferably, the surrounding media properties are also known. The chimney is then tested to a moderate pressure by injecting air containing a tracer gas. During this test, the gas injection rate, source pressure and tracer gas arrivals are carefully measured. Resulting pressure histories and tracer gas arrivals are then calculated at points of interest. A two-dimensional finite element, time-dependent diffusion code is used in an iterative manner to aid in determining relative gas permeabilities and porosities consistent with the measured data. Specifically, a set of material properties is selected. A calculation is then made using this set of material properties and the known injection rates. Calculated pressures are then compared with the experimentally measured pressures taken during both the pressurization and decay periods. Various sets of material properties are selected until the calculated and measured pressures agree. Once agreement is attained, the iteration is complete, and those material properties are assumed to be correct for the assumed geometry.

A description of the analytical, numerical technique is given in Reference 2. Briefly, the model assumes air motion within the chimney satisfies a simple Darcy flow relation while the water, contained in the relatively highly saturated chimney material, is immobile. Gas flow occurs primarily through fractures predominantly introduced during the chimney collapse. In contrast, at the low test pressures, the water is trapped within the individual rubble pieces by capillary forces. Experimental results indicate this model is reasonable. There is little water migration during the pressure test as evidenced by the repeatability of the Ming Blade data. These pressurization tests therefore measure gas flow through a partially saturated system. In that context the material flow properties are referred to in terms of the relative gas permeability and porosity since the water is immobile and has not been considered in the data interpretation technique. It should be emphasized that these relative properties do not represent a dry permeability or porosity. If the grain and in-situ densities are determined (from core samples, etc) then the dry quantities can be inferred from the relative gas permeabilities and porosities.

Three acceptable distributions of material properties have been determined for the Ming Blade chimney. All results were obtained using the following constraints:

- The chimney geometry is that shown in Figure 1.
- The material properties, for the region surrounding the chimney are taken as shown in Figure 1.
- The mass flow of air into the chimney is that measured during the test.
- The pressure and tracer gas measurements obtained at U12n.08 RE#1 , RE#2 , and PS#1 are taken to represent conditions along these holes either at the chimney ℄ or adjacent to the chimney boundary as is appropriate.

The previously described analytical/numerical model can reproduce the experimentally measured pressure histories using any of the relative gas permeability and porosity distributions shown in Figures 8 through 10. The corresponding comparisons between the calculated and experimentally measured pressure histories are shown in Figures 11 through 13, respectively. Three acceptable solutions are presented. The first two assume there exists no radial variations in material properties within the chimney and their differences result because of anomalies in the measured pressure histories. The third assumes there exists a highly fractured layer adjacent to the chimney boundary. All solutions are equally compatible with the available Ming Blade data. To determine which solution is more correct requires additional data. Results of a study conducted to determine the sensitivity of the predicted values for the relative gas permeabilities and porosities are given in Appendix I.

Solutions shown represent the best representations to the experimental data obtained after numerous calculations. Results shown in Figures 8 and 11 represent the best interpretation of the Ming Blade data obtained during the second test. Although the comparison between calculation and experiment is reasonably good, the chimney properties shown in these figures are not consistent with all experimental data. Specifically, some pressure measurements made by DNA while injecting gas in U-12n.08 PS#1 imply a high relative permeability (i.e., $\geq$ 50 darcies) in the upper chimney region. Unfortunately, there exist some anomalies in that pressure data. However, as shown in Figure 9 and 12, a high value for the permeability can equally well be assumed for the upper chimney region if there exists some low permeability layer between U-12n.08 PS#1 and U12n.08 RE#1 holes . A possible third solution was obtained by assuming there existed a highly permeable layer near the chimney boundary as shown in Figure 10. A comparison of the calculated and predicted pressure histories assuming this geometry is shown in Figure 13. In the results presented in Figures 8 through 13 the

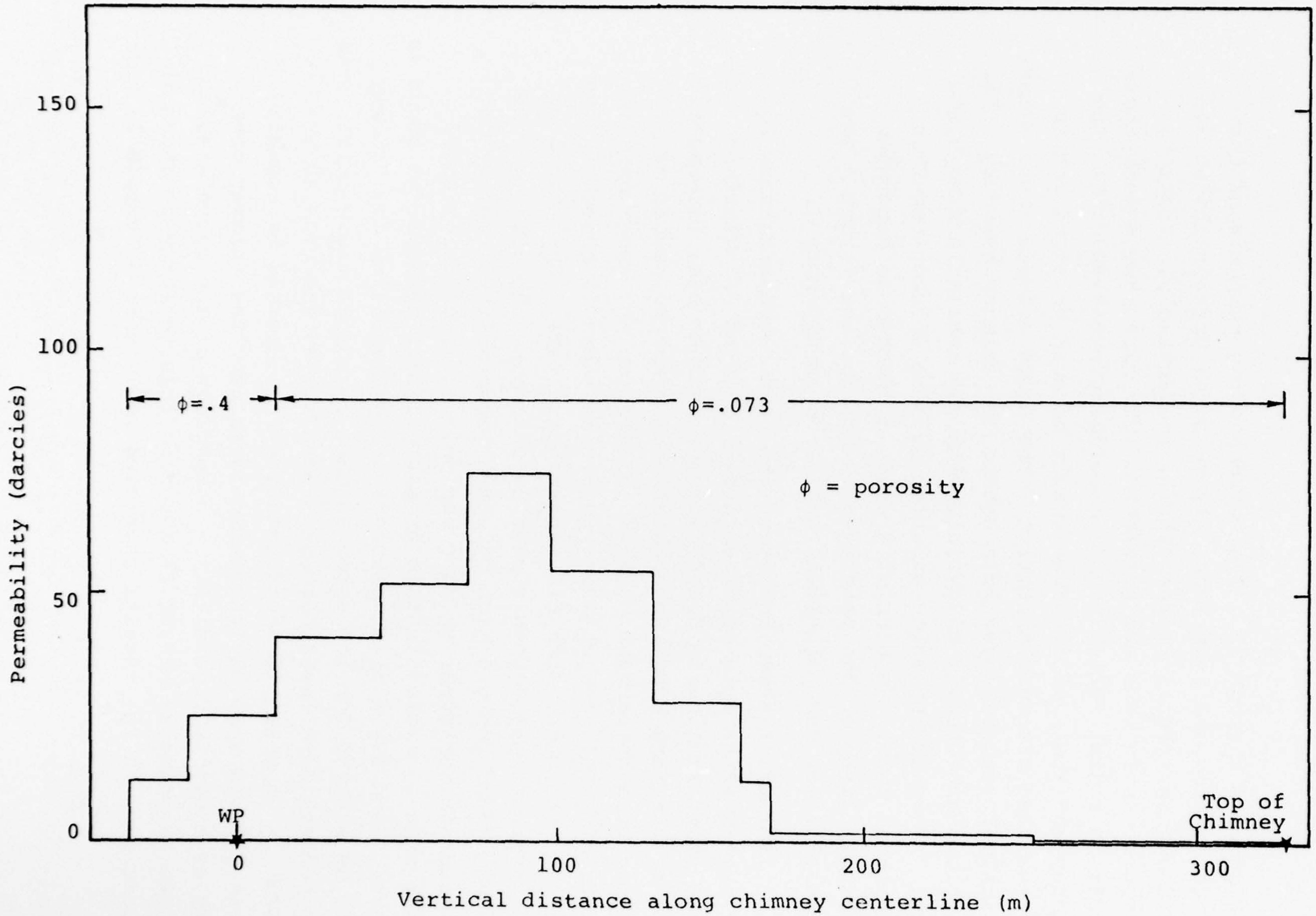


Figure 8. Values of relative gas permeability and porosity used to obtain calculated chimney pressure history shown in Figure 11.

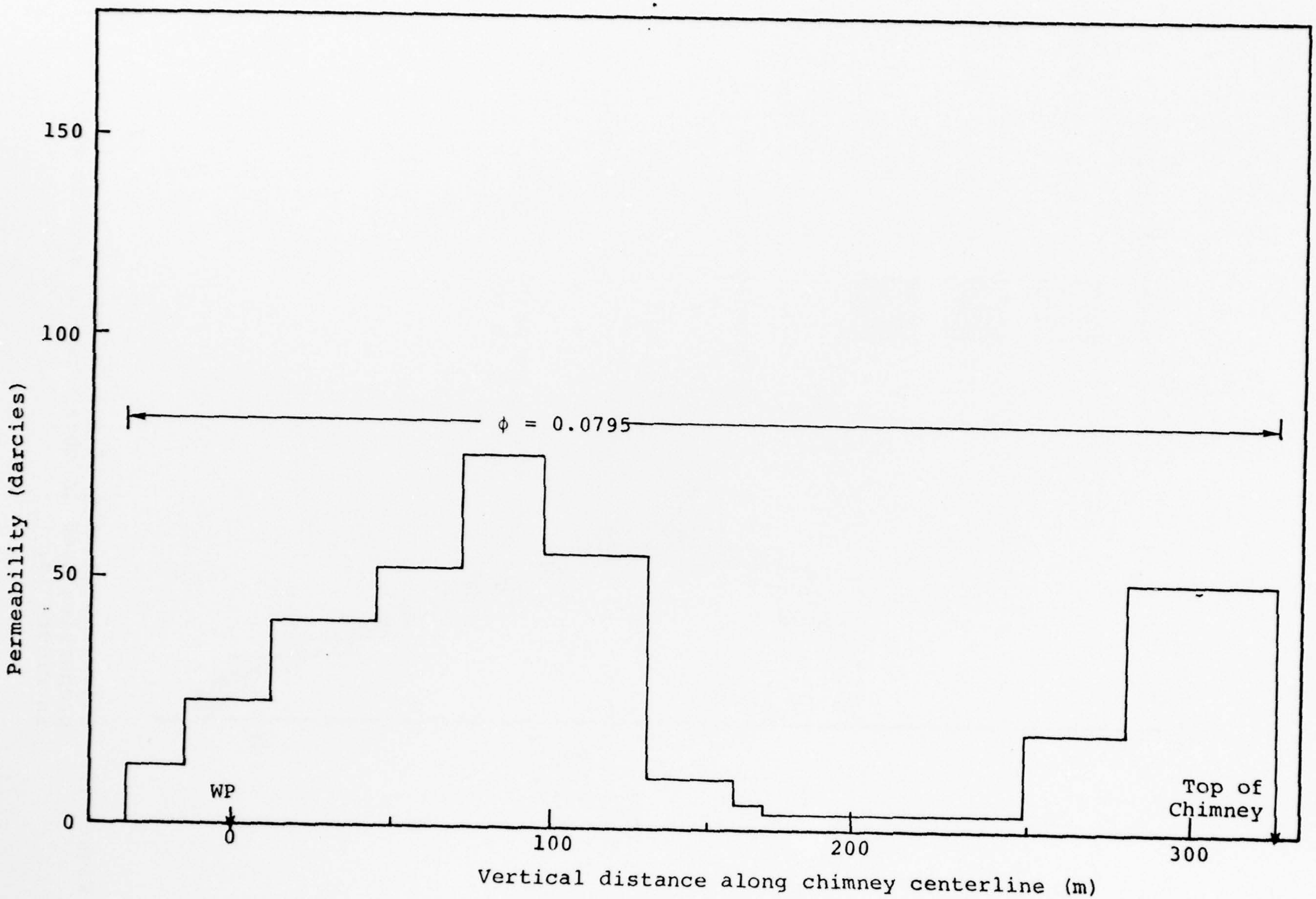


Figure 9. Values of relative gas permeability and porosity used to obtain chimney pressure history shown in Figure 12.

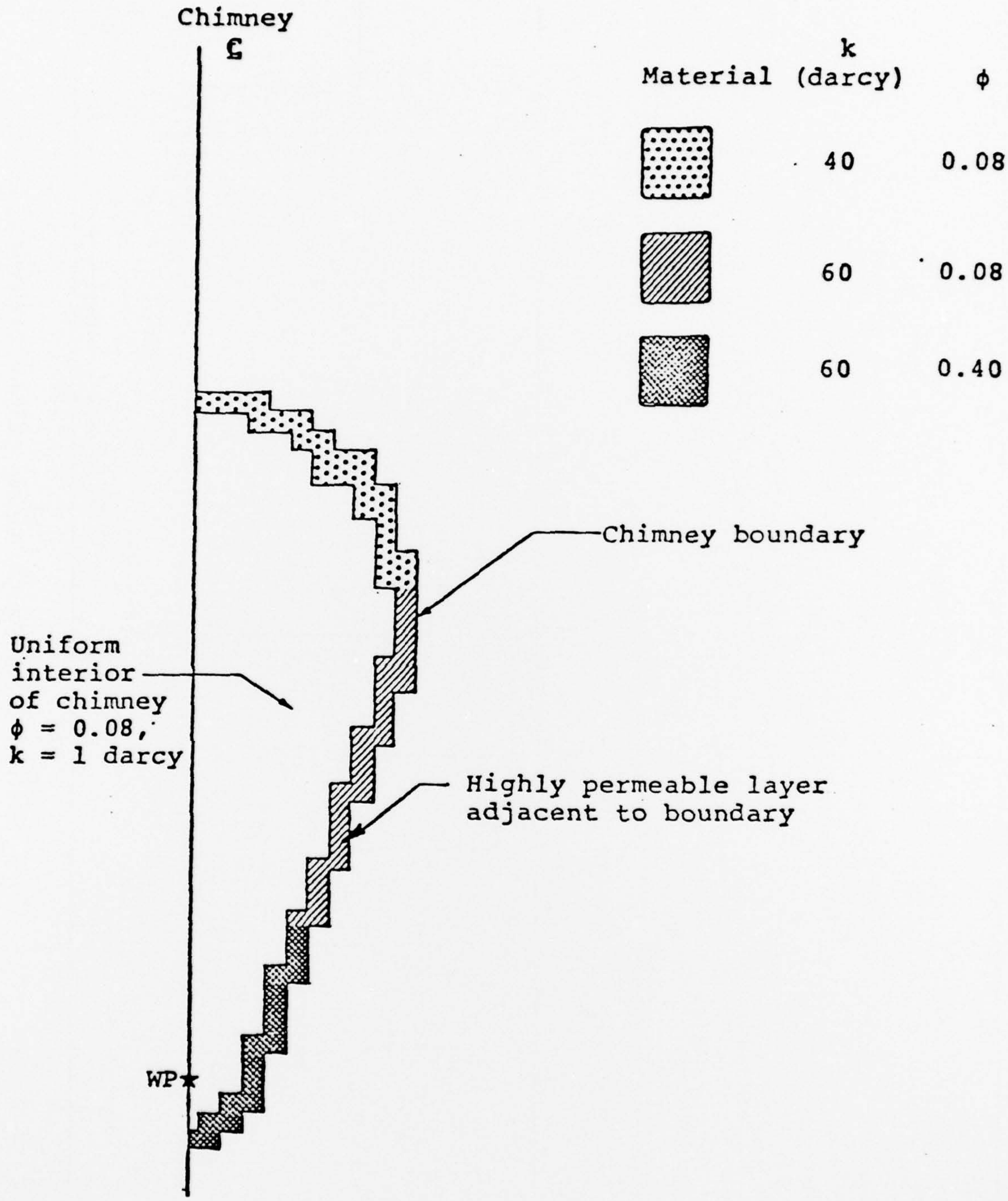


Figure 10. Illustration of grid and definition of material properties used in obtaining the results shown in Figure 13.

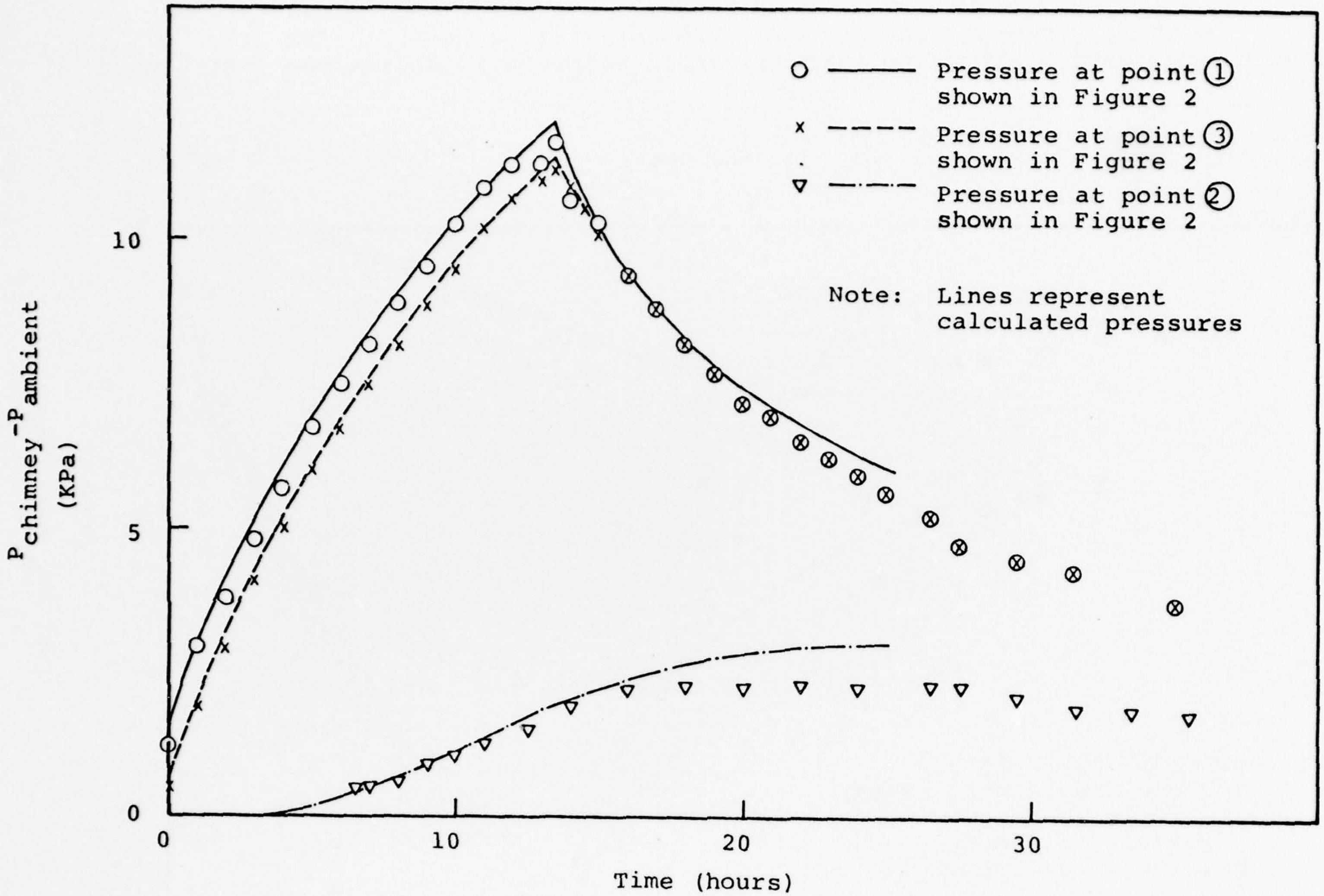


Figure 11. Comparison of measured pressures with calculated values obtained using values of relative gas porosity and permeability shown in Figures 1 and 8.

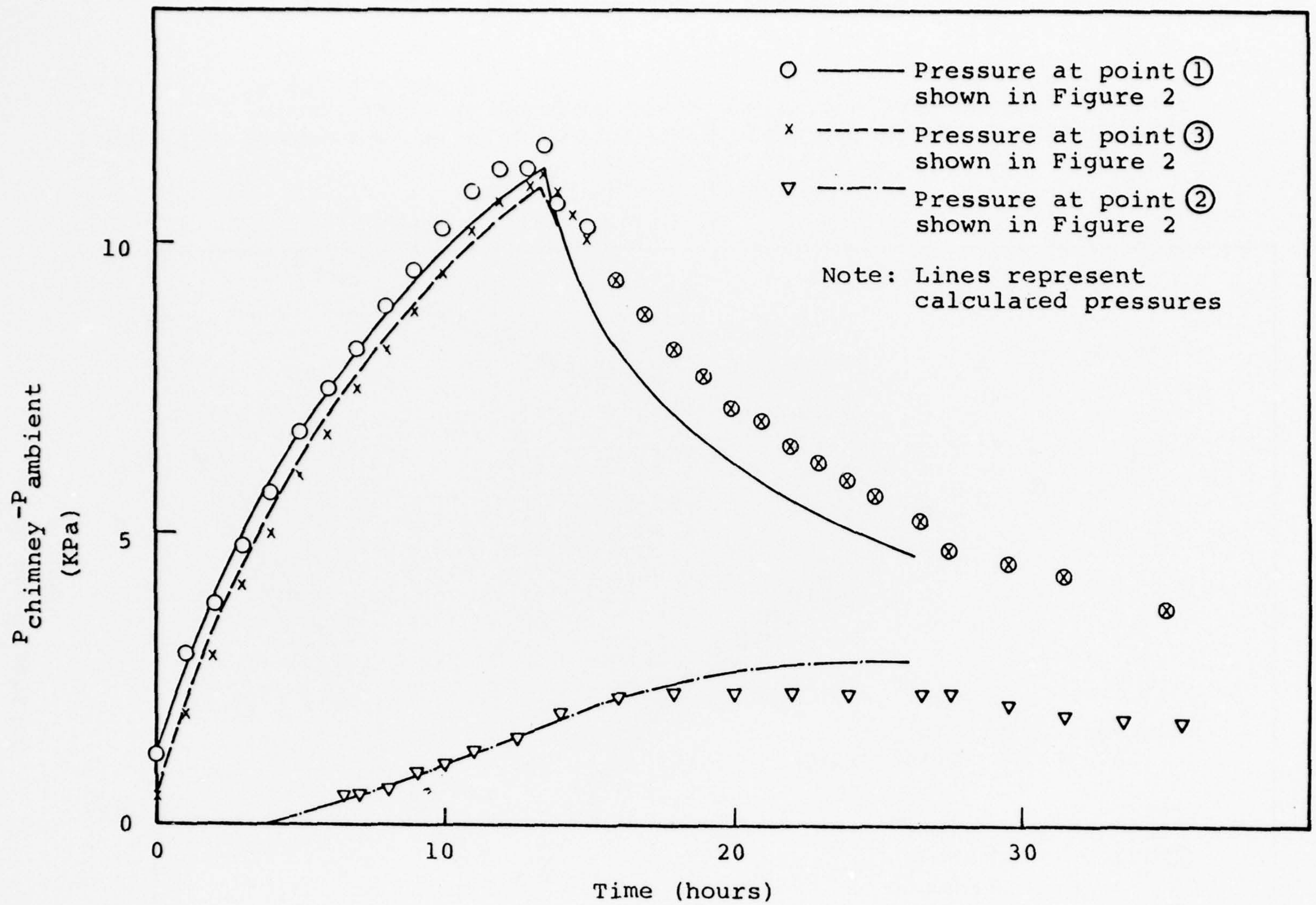


Figure 12. Comparison of measured pressures with calculated values obtained using values of relative gas porosity and permeability shown in Figures 1 and 9.

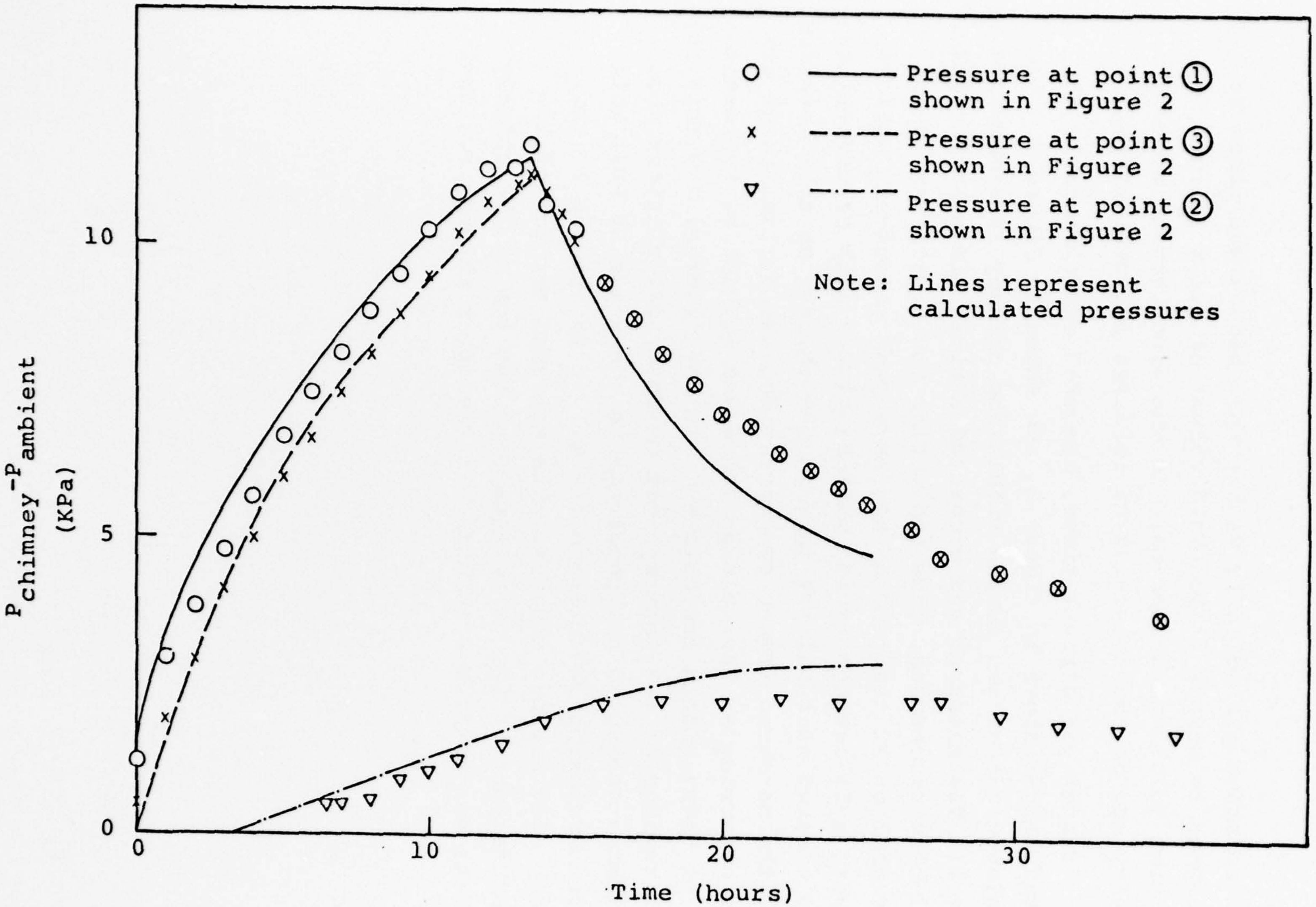


Figure 13. Comparison of measured pressures with calculated values obtained using values of relative gas porosity and permeability shown in Figures 1 and 10.

total relative air porosity within the chimney was taken to correspond to an air filled void volume of 5.4×10^5 m^3. The three solutions differ only in the distribution of this porosity and in the selection of relative permeabilities.

Tracer gas arrival times, measured experimentally at points ② and ③ shown in Figure 2, are shown in Figure 7. The calculated tracer gas motion within the chimney is summarized in Table 1. The measured and predicted arrival times at the U12n.08 RE #2 hole correspond, thus indicating the fracturing in the lower portion of the chimney may have been relatively uniform. However, this interpretation must be viewed with caution since there existed no capillary tube to the chimney at this location. Thus, the measured tracer concentrations and arrival times are those occurring at the hole entrance and may not be representative of those within the chimney. If the fracturing within the upper regions of the chimney were uniform, calculations show the tracer-gas would not penetrate to the U-12n.08 PS#1 hole (which terminates 220 m above the WP) or to the top of the chimney (320 m above the WP). The measured arrival of low concentrations of the tracer gases at the top of the chimney indicate non-uniform fracturing in the upper chimney regions.

Table 1.

Tracer Gas Penetration within the Chimney.

Study	Time (hours)	Highest Position of Tracer Relative to WP	Lowest Position of Tracer Relative to WP
Figures 8 and 11	0 (Flow on)	296 ft	183 ft
	14 (Flow off)	489	-17
	24	500	17
Figures 9 and 12	0	296	183
	14	468	14
	24	480	26
Figures 10 and 13	0	183*	183*
	14	416	148**
	24	488	163**

*The flow to the top portion of the chimney is primarily along the highly permeable layer adjacent to the chimney wall. The U12n.08 RE #1 hole intersects this region approximately 183 ft above the WP or 113 ft below the level at which it intersects the chimney ℄. Although the rate at which tracer-gas travels in the vertical direction is higher in Case #3, the source position is lower. The net result is that the vertical penetration of tracer-gas is approximately the same in all three cases.

**The downward penetration is greater than indicated since the tracer particles did "hang up" on the wall during the calculation. Rough estimates indicate the tracer-gas should penetrate to approximately the WP level by this time.

REFERENCES

1. Peterson, E., _et al._, "Gas Flow Calculations for the Ming Blade Chimney - Preliminary Calculational Results," Systems, Science and Software Report SSS-R-76-2170, November 1975.

2. Peterson, E., _et al._, "Summary of the Dining Car Tracer-Gas Chimney-Pressurization Studies," Systems, Science and Software Report SSS-R-77-3185, April 1977.

APPENDIX I

To provide an indication of the accuracy of the material properties selected in Section 5, the results of calculations completed using three different sets of relative gas permeabilities and porosities will be presented here. The basis for comparison for this sensitivity study are the pressure histories shown in Figure 12, which were obtained using the material properties shown in Figure 9.

The effect of uniformly doubling the chimney porosity while maintaining the same permeability distribution is shown in Figure I-1. Since a fixed amount of air is injected into the chimney, increasing the porosity reduces chimney pressures. As expected, decreasing the porosity will increase chimney pressures as illustrated in Figure I-2. The pressure distribution within the chimney can be further manipulated by changing permeability values. For the results presented in Figure I-3, a uniform porosity of 0.16 was assumed. The permeability was then varied throughout the chimney as required to obtain numerical results compatible with measured pressure values. Given $\phi = 0.16$, Figure I-3 represents the best comparison which could be obtained. Corresponding permeability values are shown in Figure I-4. It is seen that the data interpretation is quite sensitive to the selected porosity and permeability values. Even changes in relative gas porosity as low as 25 percent result in easily noticeable deviations between the measured and calculated results. A more detailed discussion of the sensitivity of the data reduction methods is included in Reference 2.

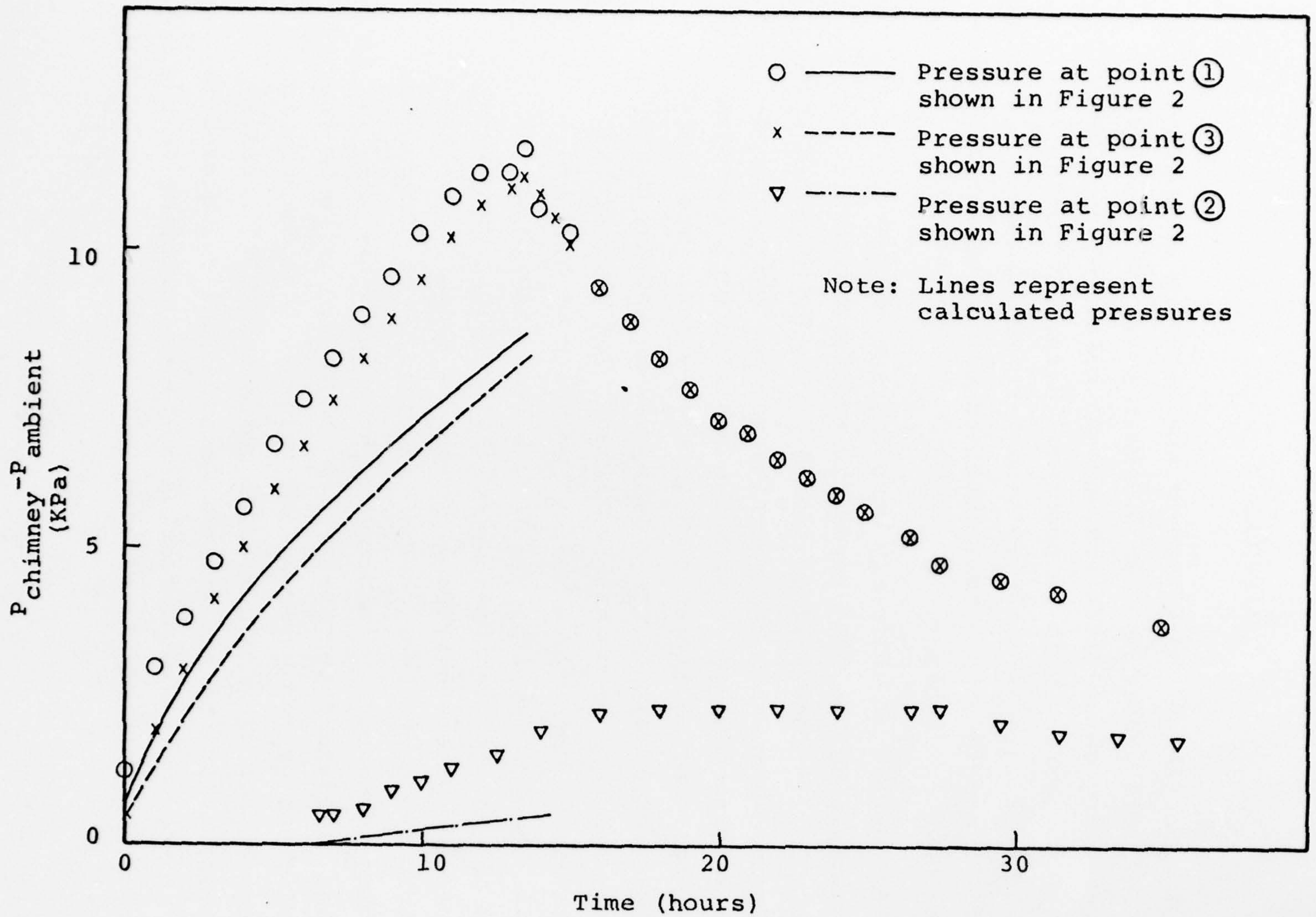


Figure I-1. Comparison of measured chimney pressures with calculated values obtained assuming a relative gas porosity within the chimney of 0.16 and the relative permeability distribution shown in Figure 9.

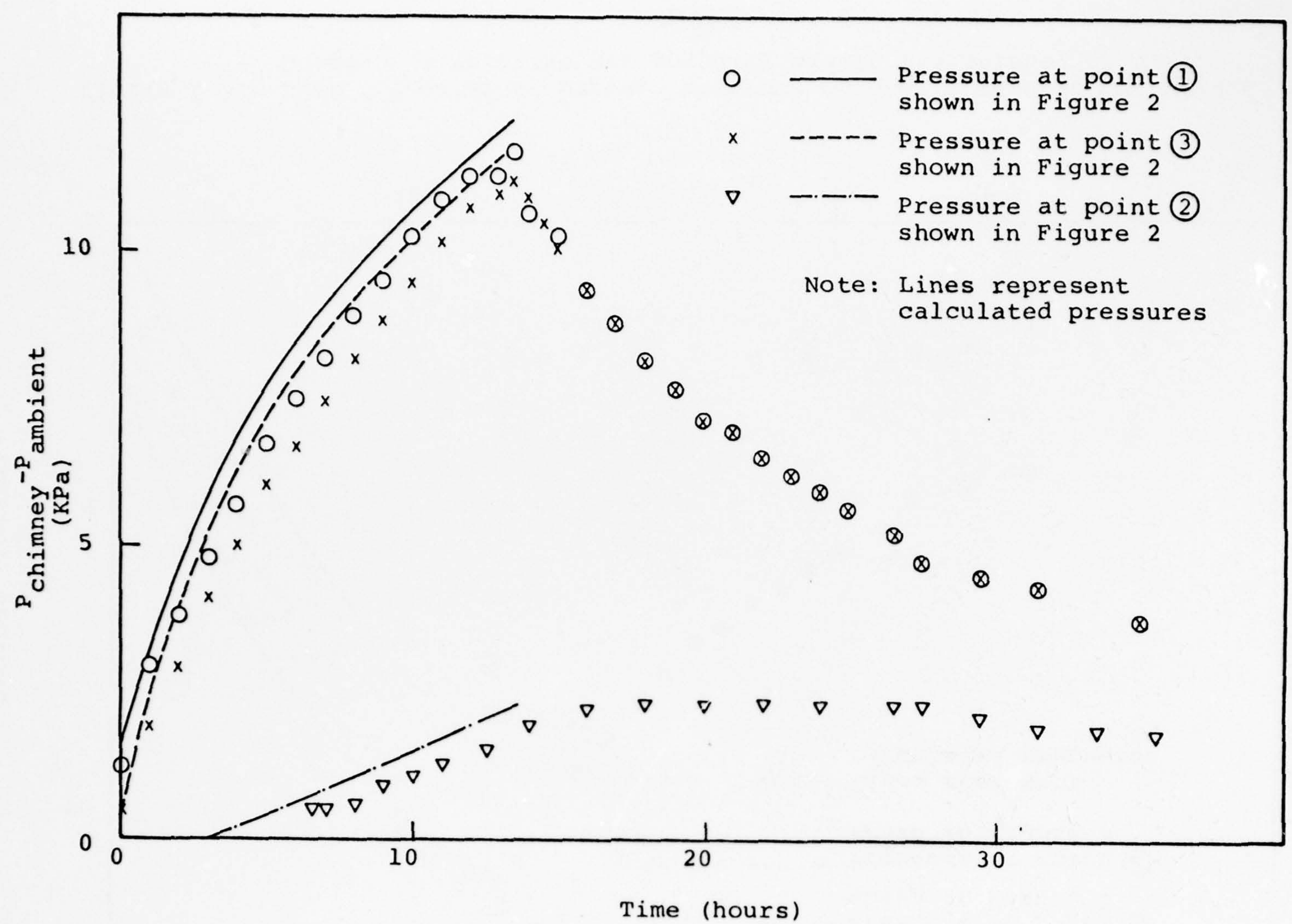


Figure I-2. Comparison of measured chimney pressures with calculated values obtained assuming a relative gas porosity within the chimney of 0.06 and the relative permeability distribution shown in Figure 9.

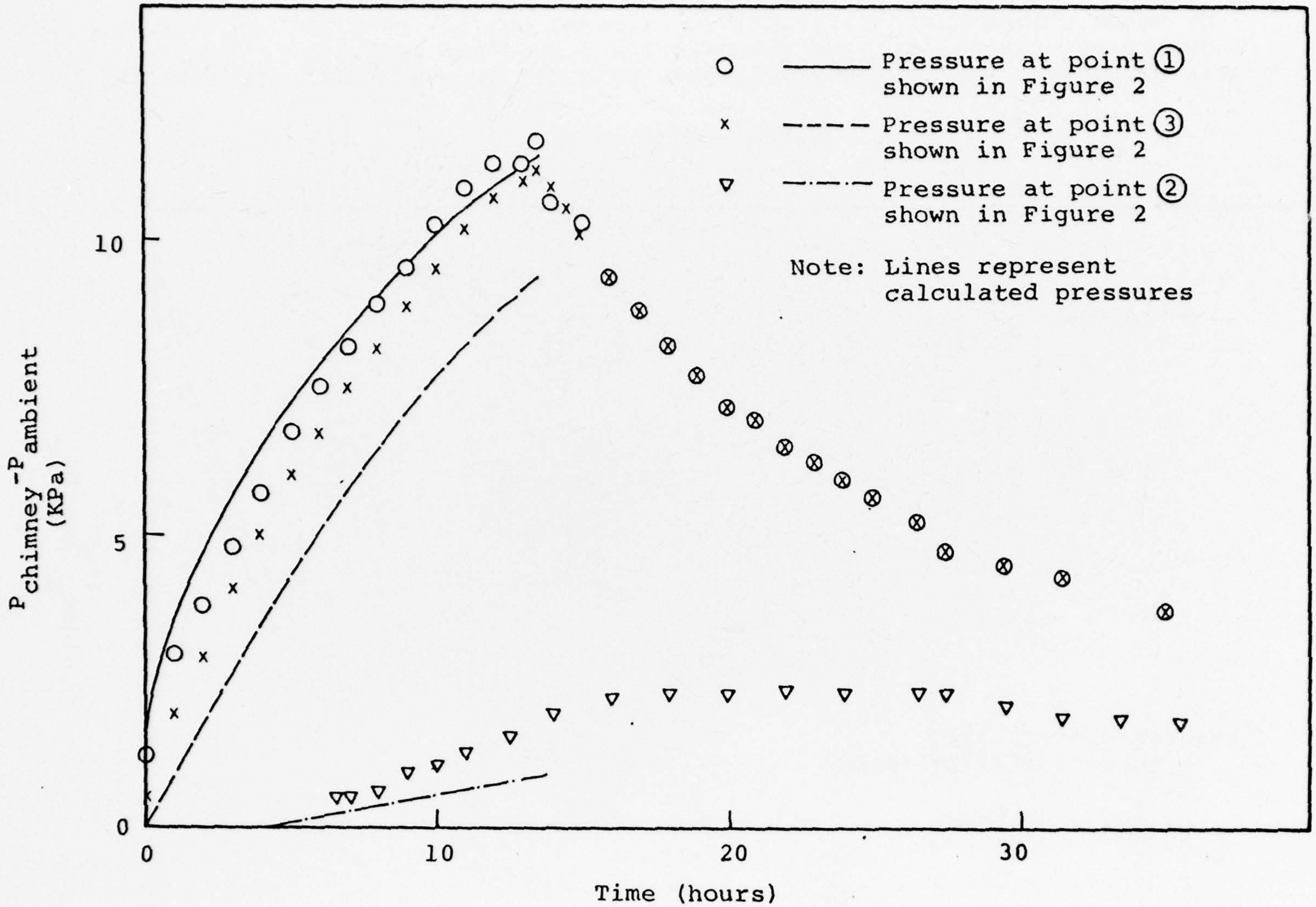


Figure I-3. Best fit obtained between measured chimney pressures and values based on a relative gas porosity within the chimney of 0.16.

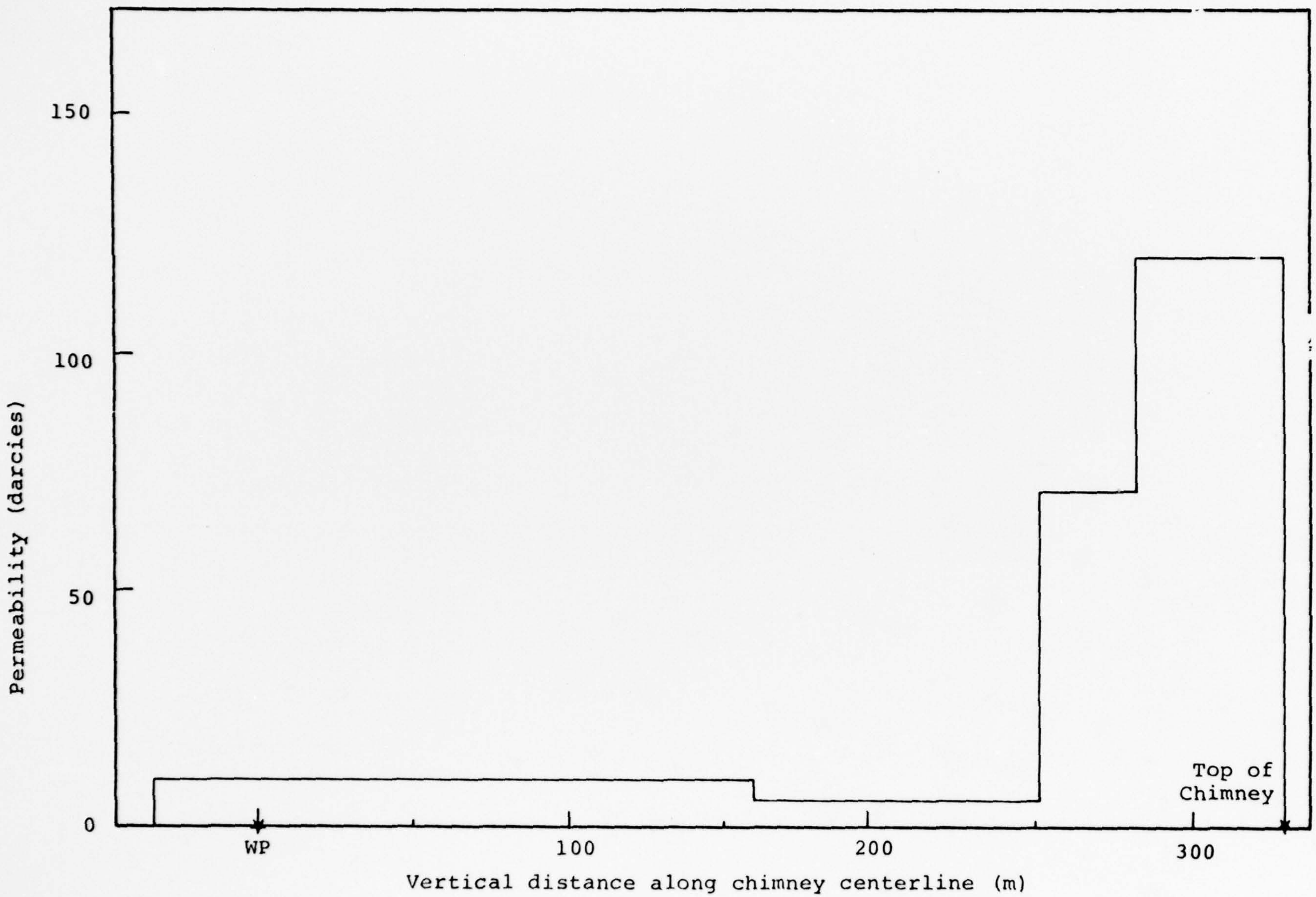


Figure I-4. Values of relative permeability used to obtain pressure data shown in Figure I-3.

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